Space Weather Technical Forecast

Issued on Saturday, 16 December 2023 at 13:09 Local

This technical forecast provides a four day assessment of space weather events. The probabilities stated below are for reaching or exceeding the given levels. For more information about space weather impacts please see the Met Office Space Weather Scales https://www.metoffice.gov.uk/weather/learn-about/space-weather/uk-scales

Space Weather Forecast Headline: M-flares likely, and chance of X-flares (R1-R3). G1-G2/Minor-Moderate Storms possible Days 1 and 2 (16-17 Dec) with CME arrivals, slight chance of G3/Strong Storms. Chance for S1/Minor Radiation Storm on Days 1 and 2 (16-17 Dec), risk reducing later in the period.

Analysis of Space Weather Activity over past 24 hours

Solar Activity: Activity has been Low with only C-class flares observed in the past 24hrs, peaking with a C5.4 from AR35314 at 15/2129 UTC. This was the region also responsible for an X-flare on the 14 Dec. There are ten sunspot regions, with the most significant being AR3514. This region does look as though it is decaying slightly, appearing to lose its delta spot, although it is becoming difficult to tell as it continues to rotate towards the western limb. SDO imagery continues to show magnetic looping across the region. AR3519 has grown recently, but is not significantly magnetically complex. The other regions remain much smaller and simpler, although a couple of new regions are appearing near the east limb and may be more complex than can currently be seen.

A filament eruption near south centre disc occurred around 15/2100 UTC. We are awaiting imagery to see if any CME was produced from this, with its location suggesting that it might contain an Earth-directed component if so.

Solar Wind / Geomagnetic Activity: Solar winds, as measured by ACE and DSCOVR at L1, continued to show the effects of a weak CME arrival at 15/1057 UTC. Wind speeds varied between 370-520 km/s after the CME arrived, but have since settled to around 470-500 km/s. Density has generally been above average, briefly dipping to average at times. The interplanetary magnetic field (IMF), Bt, was initially moderate to strong after the CME arrived with a peak of 23nT. It has since dropped to weak levels, around 5-8nT. The north-south component, Bz, initially varied mostly moderately after the CME arrival, between +17 and -13nT, before becoming weak, now varying between +7 and -2nT. The Phi angle was predominantly positive (away from the Sun). Geomagnetic activity was Quiet-Unsettled (Kp1-3).

Energetic Particles / Solar Radiation: GOES16 high energy (greater than 10MeV) proton flux gradually rose above the S1/Minor Radiation Storm level, peaking at 13 pfu at 16/0015 UTC, in response to the recent larger flares from AR3514. It has since dropped back to moderate levels. GOES16 high energy (greater than 2MeV) electron flux was mostly at background levels, with a brief moderate peak. The 24-hour fluence was well below the Active threshold (1e8 integrated pfu). The observation at 16/0000UTC was 4.03e6 integrated pfu.

Four-Day Space Weather Forecast Summary

Solar Activity: Moderate to High activity expected with the ongoing likelihood of M-class (R1-R2) flares and a chance of further isolated X-class (R3) flares from AR3514. This risk recedes later Day 2 and through Day 3 (17-18 Dec) as the region rotates off the disc.

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Solar Wind / Geomagnetic Activity: There are a number of possible Earth-directed CMEs. The first was expected to arrive early Day 1 (16 Dec) and may still arrive, but any impact is likely to be limited due to the faint nature of the CME. This may have been the cause of the weak CME arrival observed on 15 Dec but this is uncertain, and hence is low confidence. The X2.8 flare from AR3514 produced a moderately fast CME which is likely to have an Earth-directed component, most probably arriving early on Day 2 (17 Dec). However confidence in this analysis is rather low. A further weak CME early on 14 Dec looks to be cannibalised by the X-flare CME. It is possible that there is some weak fast wind influence from CH79/+ at present, but largely masked by the recent weak CME arrival. CH82/+ may then enhance the solar wind speed to elevated levels on Day 3 or more likely Day 4 (18-19 Dec).

Geomagnetic activity is expected to be Unsettled at first, possibly rising to give spells of Active to G1/Minor Storm early on Day 1 with the first forecast CME arrival. The second CME arrival is likely to give G1-G2 Minor to Moderate storms early Day 2, with a slight chance of isolated G3/Strong storm intervals. A return to mainly Quiet to Unsettled conditions is likely during Day 3, perhaps increasing again on Day 4 to Unsettled to Active with any fast wind enhancement from CH82/+.

Energetic Particles / Solar Radiation: GOES16 high energy proton flux is at moderate levels after briefly reaching S1/Minor Radiation Storm levels. There is still a risk for the proton flux to rise to these levels over Days 1-2 (16-17 Dec) if any further significant flares occur from AR3514. Forecast CME arrivals during this time may also help to increase proton levels. The risk of Radiation Storms gradually reduces later in the period as AR3514 rotates off the disc. High energy electron flux, as observed by GOES16, is currently at background levels. The forecast CME arrivals are likely to keep flux levels suppressed until Days 3-4 (18-19 Dec), when an increase is possible, however the arrival of CH82/+ will likely see further suppression of the electron belts. The associated 24hr electron fluence may start to rise Days 3-4, but is unlikely to reach the Active threshold.

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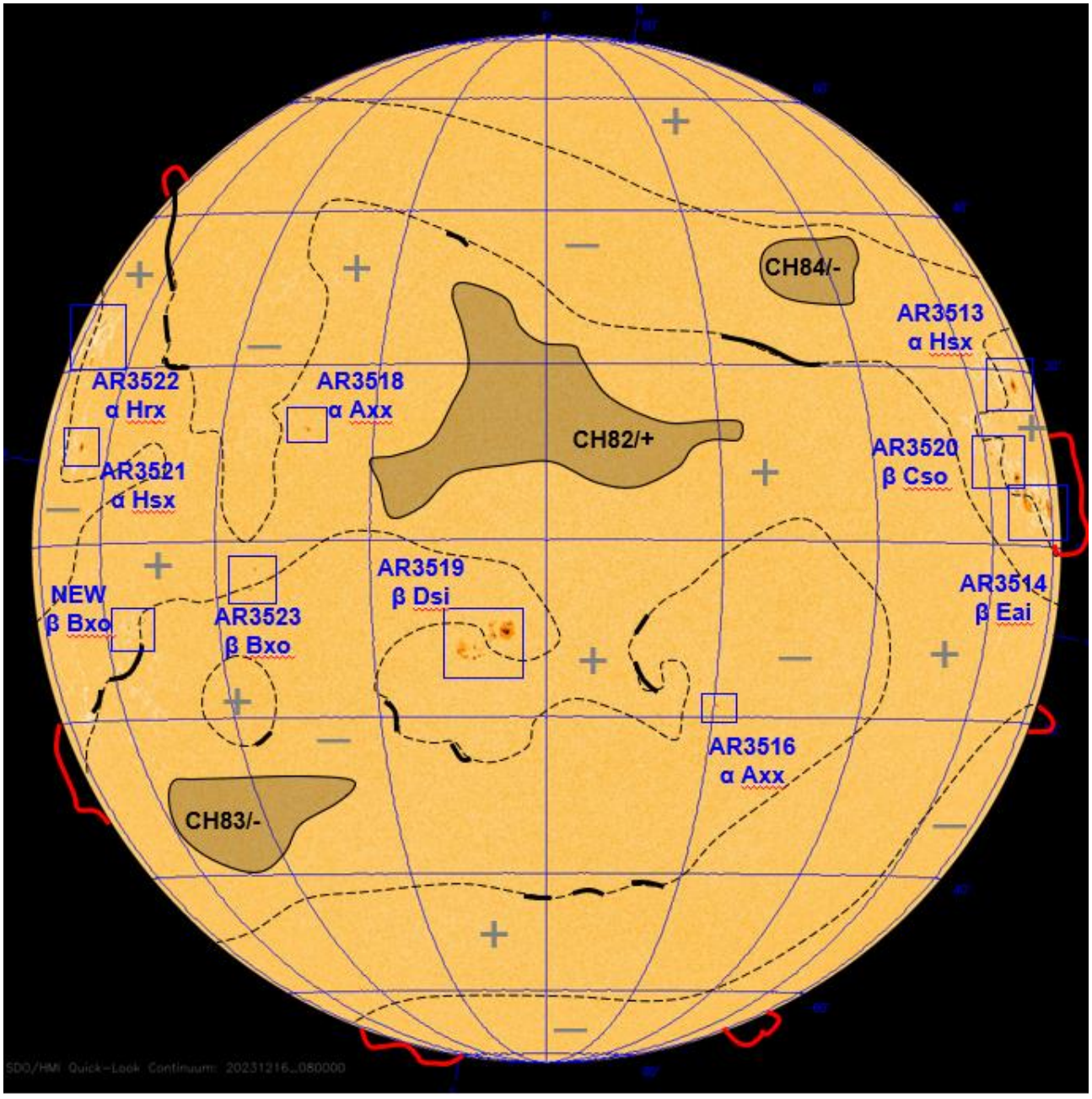
Figure 1. Solar Analysis Valid 16/0800 UTC.



Key: Filament ___ , Prominence ___ , Magnetic Field Line - - - , Polarity +/-, Coronal Holes: Grey shaded area CHxx +/-, Sunspot groups 35xx - Mt Wilson α-β-βγ-βγδ and Zurich-McIntosh Axx etc.

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Geomagnetic Storms:
A CME arrived at L1 at 15/1057 UTC. It is uncertain as to the origin of this CME, but it could either be an un-forecast CME, or potentially an early arrival of the first forecast CME mentioned below, which reduces confidence in the CME forecast somewhat.

There are a number of possible Earth-directed CMEs. One is from a filament eruption near AR3514 on 13 Dec and is expected to arrive early Day 1 (16 Dec). Any impact is likely to be limited due to the faint nature of the CME. The X2.8 flare from AR3514 at 14/1702 UTC produced a moderately fast CME which is likely to have an Earth-directed component, most probably arriving early on Day 2 (17 Dec). However confidence in this analysis is rather low. A further weak CME was observed early on 14 Dec. This was from a filament eruption off the north disc starting around 14/1109 UTC. This has been assessed, and looks to be cannibalised by the X-flare CME.

An enhancement was considered possible due to the fast wind from CH79/+, however this feature has been closing up as it crosses the visible disc. It is possible that there is some weak fast wind influence at present, but largely masked by the weak CME arrival. CH82/+ may then enhance the solar wind on Day 3 or more likely Day 4 (18-19 Dec), with this feature giving an increase in wind speeds to elevated levels on the equivalent of Day 4 on the previous rotation. Geomagnetic response to coronal holes tends to be muted at this time of year, however.

Geomagnetic activity is expected to be Quiet to Unsettled at first, possibly rising to give spells of Active to G1/Minor Storm early on Day 1 with the first forecast CME arrival. The second CME arrival is likely to give G1-G2 Minor to Moderate storms early Day 2, with a slight chance of isolated G3/Strong storm intervals. A return to mainly Quiet to Unsettled conditions is likely during Day 3 (18 Dec), perhaps increasing again to Unsettled to Active with any fast wind enhancement from CH82/+.

Geo-Magnetic Storm Probability (Exceedance)	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Minor or Moderate	G1 to G2	No	50	60	20	5
Strong	G3	No	15	20	2	1
Severe	G4	No	2	5	1	1
Extreme	G5	No	1	1	1	1

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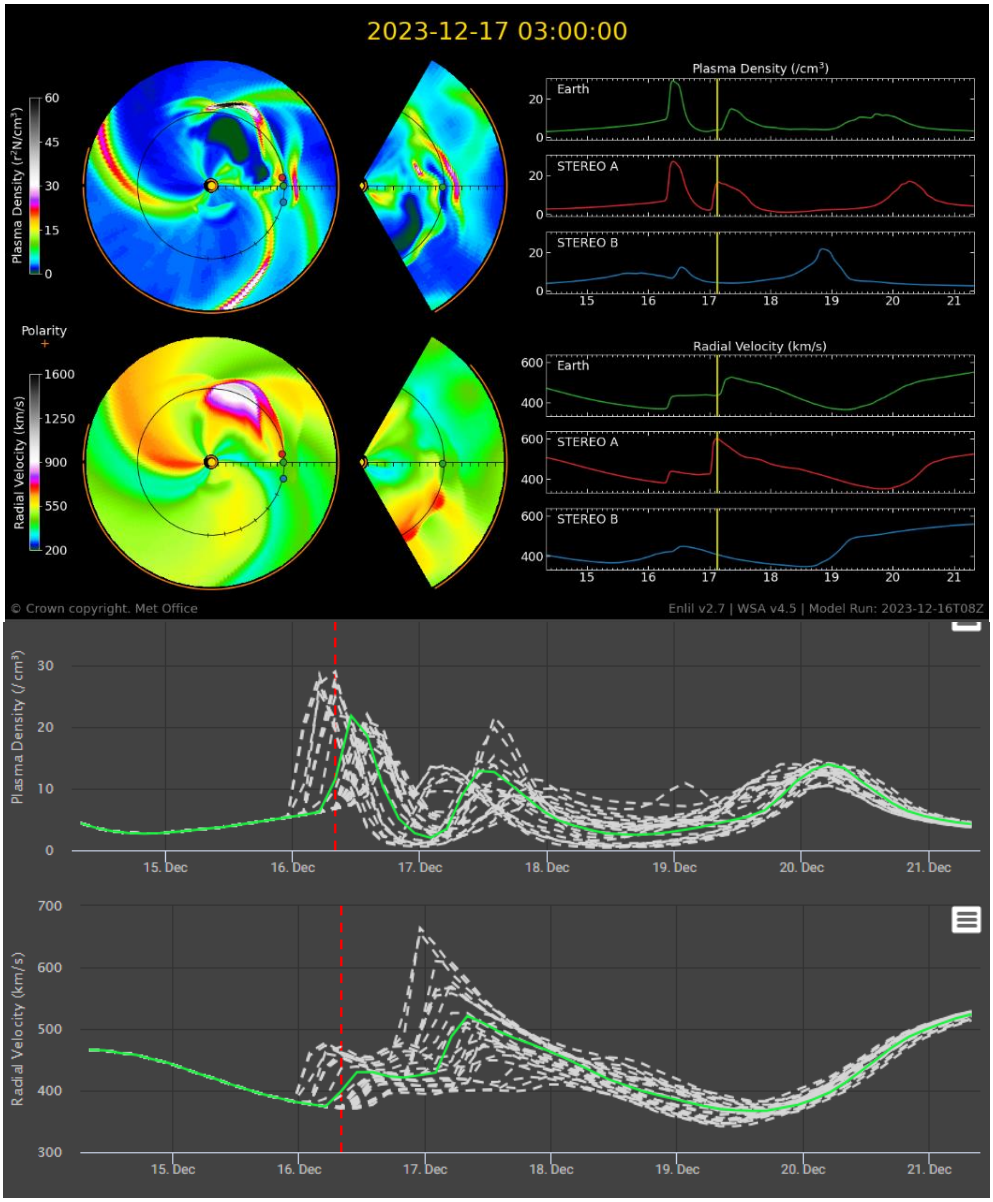
Geomagnetic Activity - Earthbound Coronal Mass Ejections

Date/time 21.5R (UTC)	Halo: Full or Partial	Source	Source Location	Estimated Speed	Estimated Arrival Time	Comments
13/0555	Partial	Filament nr AR3514	NW	530 km/s	16 Dec	Low confidence, may have arrived early on 15 Dec
14/2112	Full	X2.8 from AR3514	NW	974 km/s	Early 17 Dec	Low confidence in timings

Figure 2: MOSWOC Enlil and Ensembles showing forecast CME arrivals



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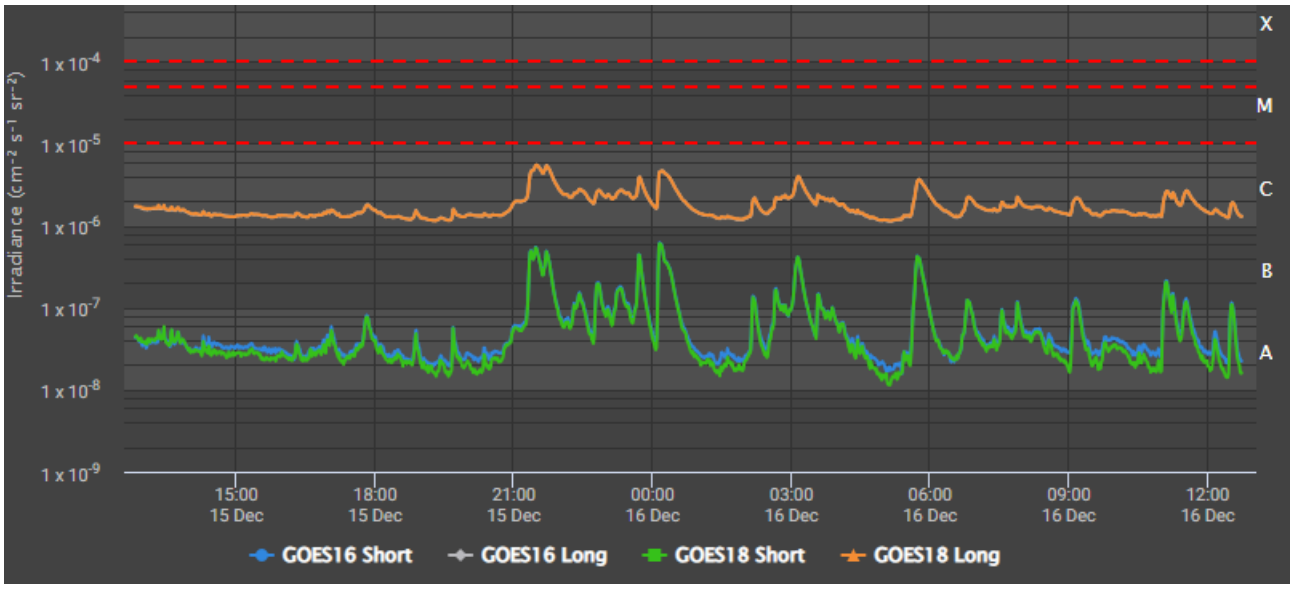
Radio Blackouts - X-Ray Flares:
Moderate to High activity is forecast, with the ongoing likelihood of M-class (R1-R2) flares and a chance of further X-class (R3) flares from AR3514. This activity is expected to decline as AR3514 rotates off the disc during Day 2 (17 Dec).

There are ten sunspot regions, with the most significant being AR3514 approaching the western limb. This region does look as though it is decaying slightly, and has probably lost its delta spot, although it is becoming difficult to pick out detail as it continues to rotate towards the western limb. SDO imagery continues to show strong magnetic looping across the region. AR3519 has grown recently, but is not significantly magnetically complex. The other regions remain much smaller and simpler.

However a couple of new regions are appearing near the east limb, again with clear magnetic looping in SDO imagery, so these regions may be more complex than can currently be seen and will continue to be assessed as they rotate further onto the visible disc.

X Ray Flares	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC)	Day 2 (00-24 UTC)	Day 3 (00-24 UTC)	Day 4 (00-24 UTC)
Probability			(%)	(%)	(%)	(%)
Active	R1-R2 M Class	No	60	60	50	40
Very Active	R3 to R5 X Class	No	25	25	10	5

Figure 3: GOES-16 & -18 X-ray flux showing Low activity C-flares over the past 24hrs.



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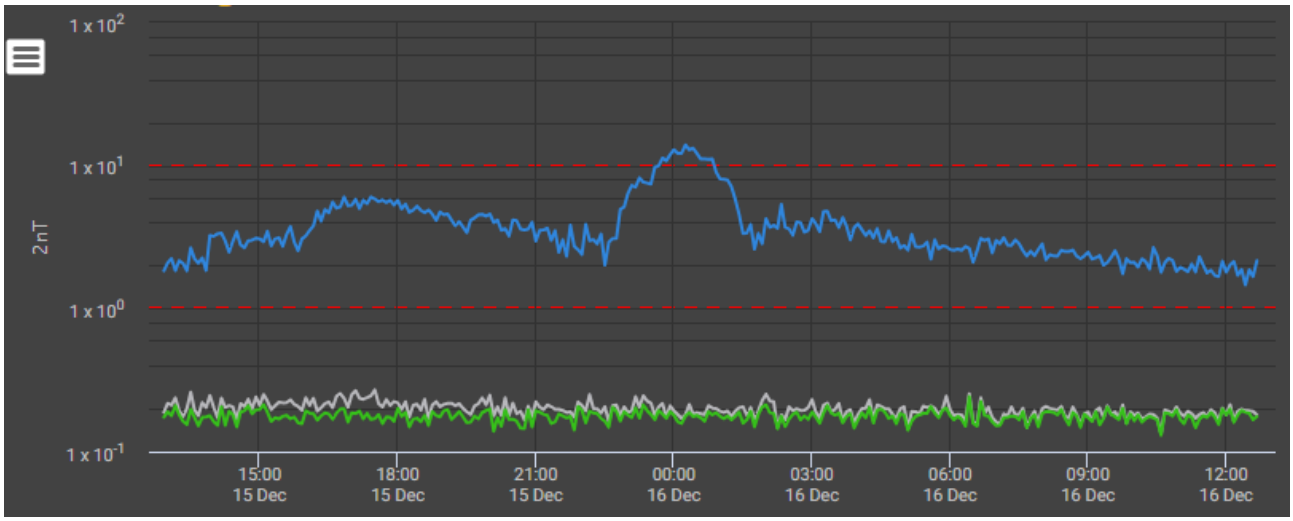
Solar Radiation Storms - (High Energy Protons):
The high energy (greater than 10MeV) proton flux observed by GOES16 has gradually risen after the X2.8 flare and subsequent flares from AR3514, and recently went above the S1/Minor Radiation Storm level. The flux has dropped in recent hours, but any additional flares from AR3514, as well as the arrival of any forecast CMEs over the next 24hrs, increases the risk for it to rise back to S1/Minor Radiation Storm levels. In the absence of any further flares, proton flux will likely continue to slowly decline through the coming days. AR3514 will rotate off the disc during Day 2 (17 Dec), but any far-side flares on Day 3 (18 Dec) will continue to give a risk of high energy protons, before this risk declines during Day 4 (19 Dec).

Radiation Storms Probability (Exceedance)	Level (cm^{-2} sr^{-1} s^{-1})	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	**≥ S1**	Yes	60	40	20	10
Very Active	**≥ S3 ***	No	5	5	1	1
* S3 ≥ 10 MeV ≥ 1000 pfu and / or ≥ 50 MeV ≥ 10 pfu. (pfu = $cm^{-2}sr^{-1}s^{-1}$)						

Figure 4: GOES-16 Proton flux showing a steady rise above the S1 threshold, and a subsequent declining trend.



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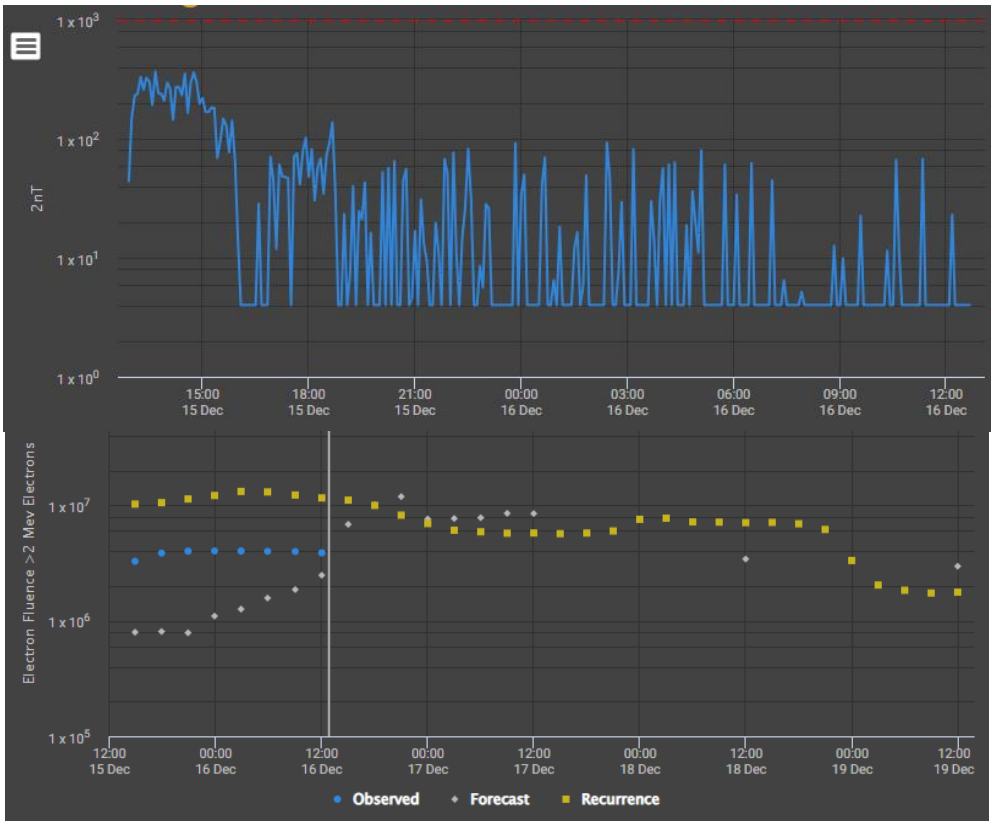
High Energy Electrons Event (≥ 2MeV):
High energy electron flux, as observed by GOES16, is currently at mostly background levels. Any current influence from CH79/+ is weak. Electron flux values at GEO are expected to remain fairly suppressed due to the likely arrival of two CMEs on Days 1-2 (16-17 Dec). As solar pressure from these features starts to ease, the observed flux may respond by increasing to moderate, perhaps peaking at high by Days 3-4 (18-19 Dec), although the next anticipated fast wind from CH82/+ may well see these values begin to be suppressed once again on Day 4.

The associated 24-hour fluence is expected to remain below the Active threshold for much of the period, as indicated by REFM, although this model doesn't take account of CME impacts. Fluence may start to rise as the CME effects wane, but with CH82/+ expected to bring fast winds around this time there is probably only a slight chance of Active fluence by the end of Day 4.

GEO Electron Environment Probability (Exceedance)	Level (cm^{-2} sr^{-1} day^{-1})	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	**≥ 2 MeV ≥ $1x10^8$**	No	1	1	10	15
Very Active	**≥ 2 MeV ≥ $1x10^9$**	No	1	1	1	1

Figure 5: GOES-16 Electron flux showing background levels, and MOSWOC REFM showing a below average forecast over the coming days.



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